SUPPLEMENTARY INFORMATION

PHASE DIAGRAM MODELING

Phase diagrams are constructed in the eleven-component MnNCKFMASHTO (MnO–Na$_2$O–CaO–K$_2$O–FeO–MgO–Al$_2$O$_3$–SiO$_2$–H$_2$O–TiO$_2$–O) model system using THERMOCALC v3.45e (Powell and Holland, 1988) and an updated version of the dataset ds6 (file tc-ds63.txt, created 05/01/2015; Holland and Powell, 2011). The activity–composition relationships for garnet, orthopyroxene and biotite are those of White et al. (2014b), ilmenite–hematite is from White et al. (2000), C1 plagioclase and K-feldspar are from Holland and Powell (2003) and muscovite is from White et al. (2014), but with a reduced $G^{\text{mod}}$ value (see notation in Green et al., 2016) for the margarite end-member of 5 kJ mol$^{-1}$ from 6.5 kJ mol$^{-1}$ (Palin et al., 2016). Augitic clinopyroxene and tonalitic melt are from Green et al. (2016). The aluminosilicates, quartz and aqueous fluid (H$_2$O) are taken as pure end-member phases. The utilised bulk compositions are listed in Tables DR1 and DR2.

Enthalpy depends on the amount of material and the absolute values calculated are a function of the bulk composition considered. An arbitrary temperature of 600 °C has been chosen as common reference point. The subsolidus part of Fig. 1D–F and DR3B has been calculated assuming fluid-saturated conditions; the extensive property of enthalpy implies that the slope of the isotherms is slightly different to the suprasolidus part. It should be noted that the relative spacing between the isotherms remains unvaried compared to the suprasolidus conditions. This indicates that in both the sub- and suprasolidus parts of the diagrams the same increase in enthalpy generally produces the same increment in temperature. Figure DR3 shows the pressure-enthalpy diagrams contoured for temperature for the refractory granite (Fig. DR3A) and the fertile metapelite (Fig. DR3B). Figure DR4 illustrates the relationship between temperature and heating rate in function of variable heat production ($S$).
THERMAL MODEL

The model is based on the formulation that describes the rate of temperature change due to heat input

\[ \frac{dT}{dt} = \frac{S}{\rho C_p} \]  \hspace{1cm} (1)

(Stüwe, 2007) where \( S \) is the volumetric rate of heat production (W m\(^{-3}\)). Prograde metamorphic reactions consume energy in order to advance (i.e. endothermic). We therefore discriminate between heat that is added (\( S \)) from heat that is consumed by the advancing reactions. \( S \) is the heat production for which we assume a range of values between 2–10 \( \mu \text{W m}^{-3} \) (Andreoli et al., 2006; Stüwe, 2007). \( \rho \) is the density (kg m\(^{-3}\)) and \( C_p \) is the heat capacity at constant pressure. The values for \( \rho \) are calculated along an isobaric heating path at 0.6 GPa assuming a closed system with full melt retention. In this simplest of cases the effect of thermal buffering is likely underestimated as melt retention neglects advective cooling via melt extraction occurring in natural systems. The values for the heat capacity \( C_p \) are calculated via

\[ C_p = \frac{\Delta H}{\Delta T} \] \hspace{1cm} (2)

for a given enthalpy (\( \Delta H \)) and temperature interval (\( \Delta T \)) on Fig. 1E, as calculated by THERMOCALC. The modelling yields the enthalpy of reaction at any point in PT space for the given bulk composition. Contrary to the latent heat of fusion (~400 kJ kg\(^{-1}\) of granite; Bea, 2012) the enthalpy of reaction also considers energy released by the crystallisation of peritectic phases (e.g. feldspars and aluminosilicates for the muscovite-breakdown) and represents a more realistic estimate for the energetics involved in the investigated reactions. The values for \( C_p \) are normalised to the molar weight of the bulk composition of Ague (1991), calculated as 0.0646 kg mol\(^{-1}\). From (1) the time parameter \( dt \) of thermal buffering is calculated for a given temperature interval via

\[ \Delta t = \frac{\Delta T \rho C_p}{S} \] \hspace{1cm} (3)

From the characteristic time scale of thermal equilibration, given by the relationship
(e.g. Stüwe, 2007) the critical length scale of thermal equilibration $L$ is estimated using $\Delta t$ calculated from (3) and taken as the time scale of thermal equilibration ($t_{eq}$). We reformulate (4) to

$$L \sim \sqrt{\kappa t_{eq}}$$  \hspace{1cm} (5)

where $\kappa$ is the thermal diffusivity ($m^2 s^{-1}$) calculated from

$$\kappa = \frac{k}{\rho C_p}$$  \hspace{1cm} (6)

assuming a constant thermal conductivity $k$ of $2.5 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$. Values for typical crystalline rocks range between $2.0–3.0 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$ (e.g. Stüwe, 2007); this range of values affects our results by $\pm 25 \%$, therefore less than an order of magnitude. Homogenous thermal conductivity is assumed for our schematic model. Density and heat capacity are calculated from the modelling.

The calculated values for the critical length scale (equation 5) for a variable heat production are plotted against temperature (Fig. 3). Fig. 4 illustrates the calculated critical length scale (equation 5, Fig. 4A) and buffering time (equation 4, Fig. 4B) for the investigated reactions as a function of heat production. Supplementary figure DR4 shows the relationship of temperature and rate of temperature increment for the investigated reactions, calculated from equation (1).

**REFERENCES CITED**


FIGURE CAPTIONS


Figure DR2. Relationship between temperature and rate of temperature increment during thermal buffering in function of external heat production (S) at 0.6 GPa. The colored shading indicates the location of reaction (1) and (2), respectively.
(A) granite + q + ksp + ilm + mt

(B) metapelite + q + pl + ilm + melt

Fig. DR1
Fig. DR2  Rate of temperature increment (K.my⁻¹)
### TABLE DR1. BULK-ROCK COMPOSITIONS (WT% OXIDES)

<table>
<thead>
<tr>
<th>Lithology</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>FeO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
<th>Fe³⁺/Fe²⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg. A-type granite*</td>
<td>73.81</td>
<td>0.26</td>
<td>12.40</td>
<td>1.24</td>
<td>1.58</td>
<td>0.06</td>
<td>0.20</td>
<td>0.75</td>
<td>4.07</td>
<td>4.65</td>
<td>0.04</td>
<td>0.41</td>
</tr>
<tr>
<td>avg. amphibolite-facies metapelite†</td>
<td>56.25</td>
<td>1.05</td>
<td>20.18</td>
<td>9.31</td>
<td>-</td>
<td>0.18</td>
<td>3.23</td>
<td>1.54</td>
<td>1.80</td>
<td>4.02</td>
<td>0.19</td>
<td>0.33</td>
</tr>
</tbody>
</table>

†Ague, 1991.

### TABLE DR2. BULK-ROCK COMPOSITIONS EMPLOYED IN PHASE EQUILIBRIA MODELLING (MOL% OXIDES). SEE TABLE DR1 FOR ORIGINAL DATA

<table>
<thead>
<tr>
<th>Lithology</th>
<th>H₂O</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>CaO*</th>
<th>MgO</th>
<th>FeO</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>TiO₂</th>
<th>MnO</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg. A-type granite†</td>
<td>0.10</td>
<td>80.35</td>
<td>7.96</td>
<td>0.81</td>
<td>0.32</td>
<td>2.21</td>
<td>3.23</td>
<td>4.30</td>
<td>0.21</td>
<td>0.06</td>
<td>0.45</td>
</tr>
<tr>
<td>avg. amphibolite-facies metapelite§</td>
<td>6.15</td>
<td>60.16</td>
<td>12.72</td>
<td>1.48</td>
<td>5.15</td>
<td>7.49</td>
<td>2.74</td>
<td>1.87</td>
<td>0.84</td>
<td>0.16</td>
<td>1.24</td>
</tr>
</tbody>
</table>

*corrected in proportion to the P₂O₅-content to account for CaO accomodated in apatite.
†Whalen et al. 1987.